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ENGINEERING EXPERIMENT STATION

AUBURN UNIVERSITY

AUBURN, ALABAMA

FINAL REPORT

PREPARED BY

GUIDANCE AND CONTROL STUDY GROUP

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SEPTEMBER 15, 1973

CONTRACT NAS8-26580
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

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FOREWORD

The Auburn University Engineering Experiment Station submitted a proposal which resulted in Contract NAS8-26580 being awarded on November 15, 1970. The contract was awarded to the Engineering Experiment Station by the George C. Marshall Space Flight Center, National Aeronautics & Space Administration, Huntsville, Alabama, and was active until September 15, 1973.

This report is a summary of the work accomplished by the Electrical Engineering Department, Auburn University, in the performance of the contract.

SUMMARY

Work on Project NAS8-26580 has proceeded in two phases. The first phase from November 15, 1970 to March 14, 1972 concentrated on selecting a scheme for attitude control of the Space Shuttle vehicle. A model-reference adaptive control scheme was chosen as being the most suitable. The second phase was conducted from March 15, 1972 to September 15, 1973. The work during this phase was divided into two major tasks:

I. Continuation of investigation of a model-reference adaptive control scheme for controlling the attitude of the Space Shuttle vehicle.

II. Investigation to determine optimum placement of the Reaction Control Jet (RCJ) engines on Space Shuttle.

Four technical reports were written and are described in Chapter II. The contract has supported four Masters students and three Ph.D. students. The publications and conference presentations resulting from work on this contract are listed in the Appendix.

PERSONNEL

The following staff members of the Electrical Engineering Department of Auburn University have actively participated in the work of this contract:

J. S. Boland, III	- Associate Professor and Project Leader
K. R. Chakravarthi	- Graduate Research Assistant
B. K. Colburn	- Graduate Research Assistant
D. M. Drinkard	- Graduate Research Assistant
M. H. Fong	- Graduate Research Assistant
J. P. Nabers	- Graduate Research Assistant
G. T. Nichols	- Associate Professor
D. W. Sutherlin	- Research Associate
L. R. White	- Graduate Research Assistant

I. INTRODUCTION

This contract was the result of a technical proposal submitted to the George C. Marshall Space Flight Center. The Electrical Engineering Department of Auburn University, under the auspices of the Engineering Experiment Station, proposed to conduct analytical studies on the theoretical aspects of thrust vector control of large space vehicles. The work was closely correlated with in-house efforts at Marshall Space Flight Center.

Areas of effort and priority of work were established by Astrionics Laboratory personnel in conferences with Auburn personnel. As the work progressed, a continuing and close liaison was maintained by making frequent trips to Huntsville for informal discussions and presentations, and by submitting technical reports as each phase of work was completed.

The project was directed by the Electrical Engineering Department. Personnel assigned to the project included faculty members of various departments, graduate students in Electrical Engineering (both PhD and MS candidates), and undergraduate students.

This report is a summary of the work performed under the contract.

II. SUMMARY OF MAJOR RESULTS IN TECHNICAL REPORTS

The major results in each of the technical reports submitted under this contract are listed below.

A. An Adaptive Control Bibliography.
First Technical Report; April 5, 1971.
An extensive adaptive control bibliography from 1963 to 1971 is presented in this report.

B. Time - Domain and Frequency - Domain Design Techniques for Model - Reference Adaptive Control Systems.
Second Technical Report; October 15, 1971.
Some problems associated with the design of model-reference adaptive control systems are considered and solutions to these problems are advanced. The stability of the adapted system is a primary consideration in the development of both the time-domain and the frequency-domain design techniques. Consequently, the use of Liapunov's direct method forms an integral part of the derivation of the design procedures. The application of sensitivity coefficients to the design of model-reference adaptive control systems is considered. An application of the design techniques developed herein is also presented.

C. Some Optimal Considerations in Attitude Control Systems
Third Technical Report; September 14, 1973.
The standard six-engine (reaction control jets) relay attitude control law with deadband is compared to an optimal weighted time-fuel attitude control law. The relay attitude control law is shown to be a good linear approximation to the weighted time-fuel optimal control law. Techniques of choosing the value of the relative weighting between time and fuel for a particular relay control law is briefly discussed also.

Vehicle attitude control laws employing control moment gyros are then investigated. An expression for the reaction torque of the gyro configuration for given gimbal angles and gimbal rates is developed. Techniques for arriving at an attitude control law by solving this expression for the gimbal rates are developed. Then, optimal linear regulator theory is applied to derive an optimal control moment gyro attitude control law. This control law has computational disadvantages in the solving of the matrix Riccati equation on a flight control computer. Several computational algorithms for solving the matrix Riccati equation are investigated with respect to accuracy, computational storage requirements, and computational speed.

D. Comparison of Thruster Configurations in Attitude Control Systems. Fourth Technical Report; September 14, 1973.

Several aspects concerning reaction control jet systems as used to govern the attitude of a spacecraft are considered. A thruster configuration currently in use is compared to several new configurations developed in this report. The method of determining the error signals which control the firing of the thrusters is also investigated. The current error determination procedure is explained and a new method is presented. Both of these procedures are applied to each of the thruster configurations which are developed and comparisons of the two methods are made.

E. Design Implementation in Model - Reference Adaptive Systems. Fifth Technical Report; September 14, 1973.

The derivation of an approximate error characteristic equation describing the transient system error response is given, along with a procedure for selecting adaptive gain parameters so as to relate to the transient error response. A detailed example of the application and implementation of these methods for a space shuttle type vehicle is included. An extension of the characteristic equation technique is used to provide an estimate of the magnitude of the maximum system error and an estimate of the time of occurrance of this maximum after a plant parameter disturbance.

Techniques for relaxing certain stability requirements and the conditions under which this can be done and still guarantee asymptotic stability of the system error are discussed. Such conditions are possible because the Liapunov methods used in the stability derivation allow for overconstraining a problem in the process of insuring stability.

Practical implementation problems such as system noise and incomplete state feedback are studied and results given in terms of a bounding criteria on the system error. Under these conditions, asymptotic stability discussions are inappropriate and instead one speaks of bounded stability or stability in the large.

III. CONCLUSIONS

The technical reports cover the major work conducted under the project. However, for work of temporary interest, several analyses, evaluations and digital computer programs were informally transmitted.

The experience gained by the staff at Auburn in working on this contract should be very valuable in conducting future studies of this nature.

APPENDIX

PUBLICATIONS AND CONFERENCE PRESENTATIONS

1. D.W. Sutherlin and J.S. Boland, III, "Design Techniques for Model-Reference Adaptive Control Systems," ASME Journal on Dynamic Systems, Measurement and Control, December, 1973.

2. J.S. Boland, III and B.K. Colburn, "Adaptive Attitude Control of the Re-Entering Space Shuttle Vehicle," The Application of Control Theory to Modern Weapons Systems Symposium, Naval Weapons Center, China Lake, California; May 9 & 10, 1973. Printed in Proceedings of the conference.

3. D.W. Sutherlin and J.S. Boland, III, "Design Techniques for Model-Reference Adaptive Control Systems," 1972 Joint Automatic Control Conference, Stanford, California; August 16-18, 1972. Printed in Proceedings of the 1972 Joint Automatic Control Conference, pp 584-590.

4. D.W. Sutherlin and J.S. Boland, III, "Design of Model-Reference Adaptive Control Systems Using Liapunov Functions," Tenth Annual IEEE Region III Convention, University of Tennessee, Knoxville, Tennessee; April 10-12, 1972. Printed in Southeastern 1972 Proceedings of the Tenth Annual IEEE Region III Convention, pp 02-1 through 02-4.

5. D.W. Sutherlin and J.S. Boland, III, "On an Extended Liapunov Design Technique for Model-Reference Adaptive Control Systems," Third Annual Houston Conference on Computer and System Science, Houston, Texas; April 26 and 27, 1971. Printed in Proceedings of the Third Annual Houston Conference on Computer and System Science, pp 172-181.

6. J.S. Boland, III, D.W. Sutherlin, and J.P. Nabers, "A Brief Survey and Bibliography on Adaptive Control," Fifth Annual Princeton Conference on Information Sciences and Systems, Princeton, New Jersey; March 25 and 26, 1971. Abstract printed in Proceedings of the Fifth Annual Princeton Conference on Information Sciences and Systems, p 409.